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Deformations of a slightly preconsolidated clay till

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ABSTRACT: With basis in the Terzaghi theory for the primary consolidation process and the introduction of creep by Taylor, a deformation model for one dimensional conditions is developed at Aalborg University, Denmark by deceased Professor Moust Jacobsen, based on results of oedometer tests with Danish clay till.

The deformation of an intact, slightly preconsolidated Danish clay till has been investigated in the laboratory by means of drained and undrained triaxial tests as well as oedometer tests, especially for studying creep deformations. In the paper the model is briefly described and examples of the use of the model on the actual clay till are given.

1 CONCEPTUAL BACKGROUND

The classic understanding of deformations in clay is, that during the first phase - the consolidation process,- the compression takes place due to changes in the effective stresses and due to the dissipation of excess pore pressure. During the secondary phase creep strain is developed under constant effective stress.

Creep deformations in clay are usually considered to vary linearly with *log t* (type I -curve Fig. 1 a)).

$$\epsilon_{cr} = \epsilon_s \, log\left(\frac{t}{t_B}\right) \tag{1}$$

with two constants, the creep rate ϵ_s and the reference time t_B.

The use of this formula involves deciding when the creep deformations actually begin. Eq. (1) cannot be used when the consolidation process and creep are assumed to run simultaneously.

For the classical time-curve Fig. 1 a) it is rather easy to find the creep rate ϵ_s as proposed by Akai or Mesri.

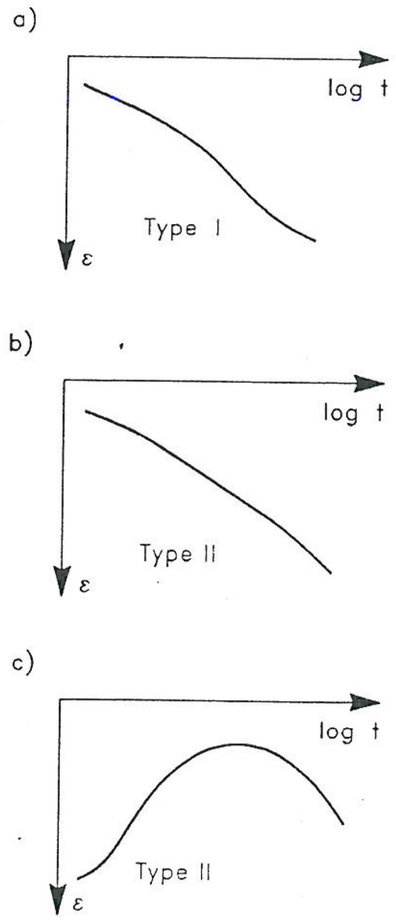

Figure 1: Typical time curves with creep. a) Classic , b) Slightly preconsolidated , c) Unloading.

Eq. (1) describes only straight lines in $\epsilon - logt$, but it is a well known fact that many creep curves bend downwards with time as the type II-curve in Fig. 1 b). For this kind of curves it is difficult to find the EOP-point, because the creep rate increases with time.

Fig. 1 c) shows a time curve from unloading. The duration of the process is very long and the shape is seldom observed.

According to deceased Professor Moust Jacobsen all creep-curves bend downwards with time with the same residual-creep rate Q_s. The curvature is only observed if the load has been active long enough. For normally consolidated clay it means a duration of $t \approx 10 \cdot t_c$ and for preconsolidated clay even longer. (For the analysed clay till $t_c = 20 - 100$ min). It means that Q_s is assumed to be a constant for all time-curves during an oedometer test.

The arbitrary creep rate ϵ_s can still represent the relative creep strain increment per time decade at a certain time. However, if the end rate for all the time curves in a test is observed at the same time, a variation of ϵ_s is still noticed with the applied stress according to Akai.

2 DEFORMATION MODEL

The two processes, consolidation and creep, are assumed to run simultaneously and independently according to Brinch Hansen 1961. Development of strain during constant loading can be described as:

$$\partial\, \epsilon = f(\sigma'\,,\, \epsilon)\, \partial\sigma' + g(\sigma'\,,\, \epsilon)\partial\, t \qquad (2)$$

where f and g are functions, dependent of σ' and ϵ.

According to Bjerrum and the derivative theories an analysis of the creep variation with time is easily implemented by assuming the primary consolidation process as instant and independent of the secondary consolidation. The creep process can be studied alone, and the primary consolidation can be added later. It can easily be tested whether the method is usable, by checking if the primary consolidation strains follow the theory of Terzaghi.

2.1 Creep deformations

The variation of the primary consolidation is first eliminated, according to Bjerrum's ideas of instant compression.

A clay loaded above the preconsolidation pressure will at $t = 0$ follow the instant compression curve, which is straight with logarithmic increment Q.

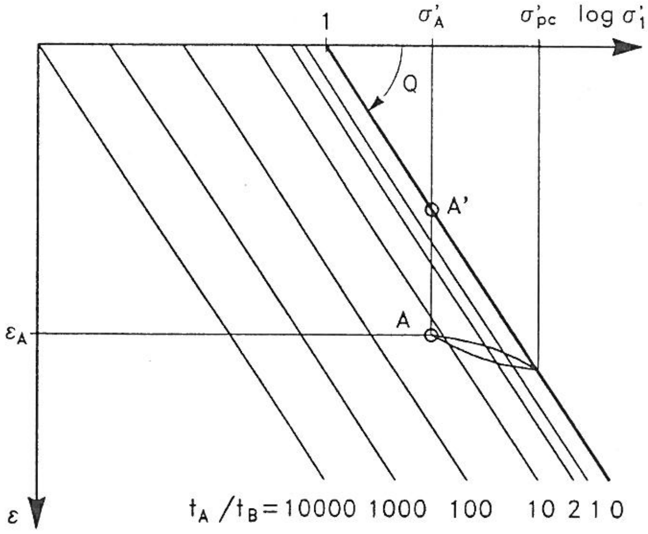

Figure 2: Behaviour of slightly preconsolidated clay (Bjerrum 1967).

At constant stress at the point A' the strain development with time can be described as

$$\epsilon_{cr} = Q_s\, log\left(1 + \frac{t'}{t_B}\right) \qquad (3)$$

where t' is the actual time passed and t_B is a reference time.

Eq. (3) shows that lines parallel to the instant compression curve are creep isochrones ($t' = const.$), because $Q_s = \alpha \cdot Q$ according to Mesri. After the time $t' = t_A$ the state A is reached. If a new time curve is observed from this point, with a new time scale t the creep-increment from this condition is

$$\Delta\epsilon_{cr} = Q_s\, log\left(1 + \frac{t}{t_A + t_B}\right) \qquad (4)$$

In the A-state the specimen will apparently be preconsolidated with σ'_{pc} found by the equation:

$$Q_s\, log\left(1 + \frac{t_A}{t_B}\right) + \frac{\sigma'_{pc} - \sigma'_A}{K_{pc}} = Q\, log\left(\frac{\sigma'_{pc}}{\sigma'_A}\right) \qquad (5)$$

where K_{pc} is the consolidation modulus for the reloading line.

2.2 Creep and consolidation as simultaneous processes

In the laboratory it is shown, according to the relatively low time of consolidation t_c, that it is possible to separate the consolidation- and the creep-process.

In principle each time curve can be analysed statistically by separating the creep process from the consolidation by means of Eq. (4). The last points of the curve are supposed to be without influence from the consolidation process. If Q_s is supposed to be a constant for the entire test the statistical analysis gives a value of t_A. Figure 3 b) demonstrates that the remaining part of the strains corresponds to a pure consolidation process following the classic theory.

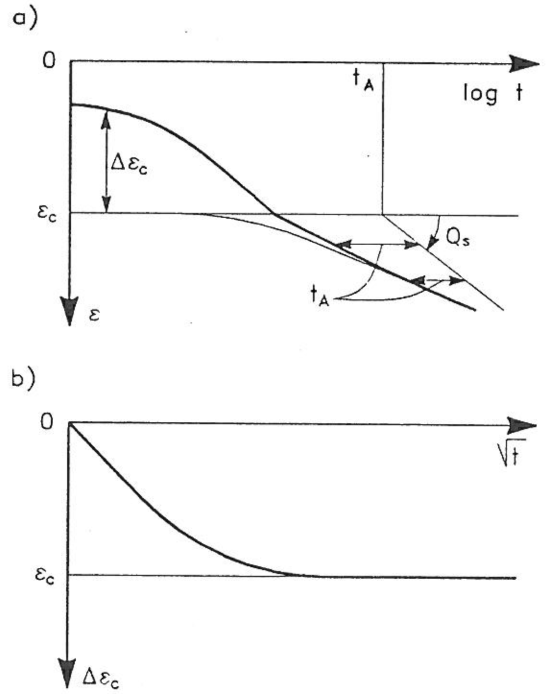

Figure 3: a) Separation of creep and consolidation, b) Primary consolidation.

Q_s is always chosen as small as possible, but big enough to describe creep for all time curves in a test. Figure 4 shows the theory used on an actual time curve.

2.3 Primary consolidation

Eq. (2) is not quite usable, because the first component cannot be described as a continuous func-

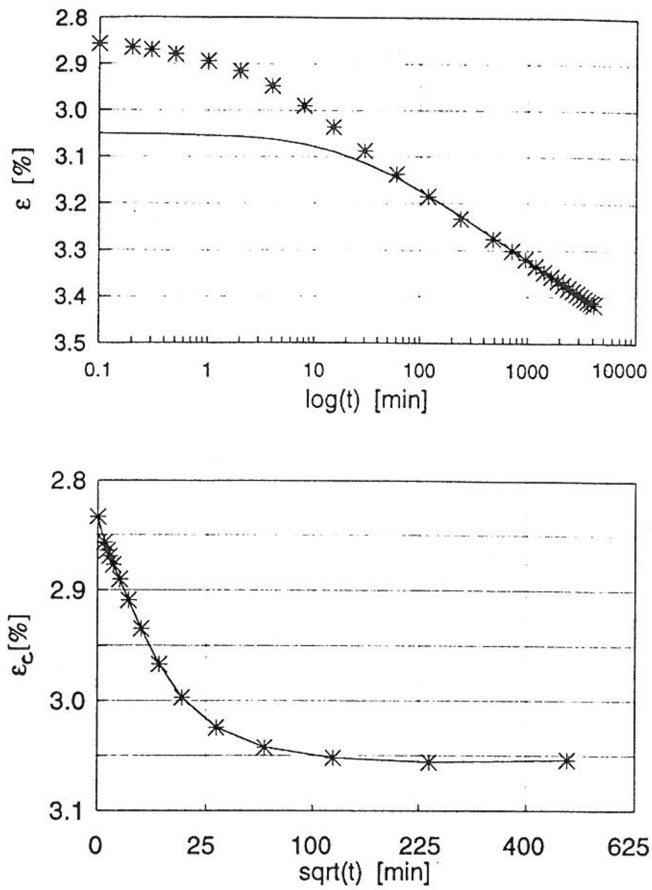

Figure 4: Separation of creep and consolidation. $\sigma' = 250 - 329$ kPa, $Q_s = 0.16\%$, $t_A = t_c = 22$ min.

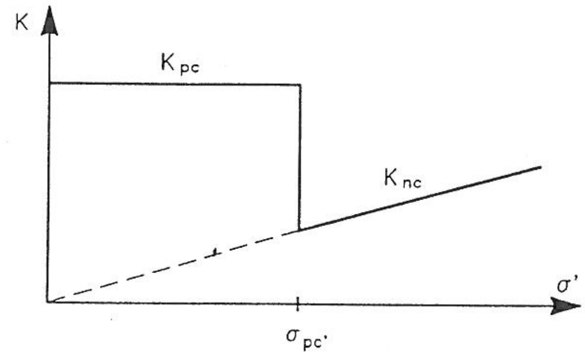

Figure 5: Variation of consolidation modulus with effective stress.

tion. It decreases drastically as the preconsolidation pressure is exceeded. The consolidation modulus $K = \Delta\sigma'/\Delta\epsilon_c$ for the primary consolidation can be described as

$$K_{pc} = Const. \qquad \text{for } \sigma' < \sigma'_{pc}$$

$$K_{nc} = \frac{ln\ 10}{Q}\sigma' \qquad \text{for } \sigma' \geq \sigma'_{pc} \tag{6}$$

where Q is the strain rate for primary consolidation in the normally consolidated state.

Calculating the variation of the modulus of consolidation with the effective stress gives a very precise method to find σ'_{pc} (Fig. 5).

3 CATEGORISATION OF CLAY

3.1 Normally consolidated clay (OCR = 1)

A clay is usually categorised as normally consolidated when the effective stress exceeds σ'_{pc}, defined as the largest applied stress. The definition can no longer be used because the creep-process starts when the load is applied, and the clay now acts as preconsolidated. It means that if the creep-process is subtracted and only the pure Terzaghi-consolidation-process is observed for a 'NC-clay' there will be a change in the slope in the $\sqrt{t} - \epsilon$-illustration for the time curve (Jørgensen 1992). It is a result of the apparent preconsolidation, obtained by creep on the previous step. The jump in modulus of consolidation by exceeding σ'_{pc} is observed on the time curve.

A new definition of the NC-state is introduced as the state, where the clay has the greatest obtainable void-ratio at a certain load. The NC-state is a limit state according to $t_A = 0$. It is necessary to measure the creep (the clay is aged) to determine if the primary consolidation process is finished.

3.2 Slightly preconsolidated clay (OCR = 1-2)

During creep a preconsolidated condition is developed described by Eq. (5) and the creep process by Eq. (4). In addition to that the slightly preconsolidated state can be obtained from the NC-state or it can be reached by unloading and subsequently reloading.

According to the theory above, $t_A = 0$ for NC-conditions but for the actual clay-till it is observed that $t_A = t_c$ if $t_B = 1$ minute. The variation of creep with time Eq. (4) is then modified to

$$\Delta\epsilon_{cr}(t) = Q_s \, log \left(1 + \frac{t}{t'_A + t_B}\right) \qquad (7)$$

where $t'_A = 0$ for the NC-state and $t_B = t_c$.

By using Eq. (7) there is no problem about the definition of the time scale when t_B is the time of consolidation t_c, both for oedometer tests in the laboratory and for foundations in the field. It can be shown that Eq. (4) and (5) do not form a consistent theory because the calculated creep deformations depend on the choise of t_B.

3.3 Preconsolidated clay (OCR = 2-10)

The preconsolidated state is reached by unloading. It is assumed that the creep can still in principle be described by Eq. (7), but the age of the creep t'_A cannot be found from the instant compression curve for the actual clay till ($Q_s = 0.15\%$, $OCR = 5$), because the observed curvature is rather small and the variation coefficient for the t'_A-fitting will be too large. For many Danish clay-types with $OCR > 2$, even for clay with greater creep rate Q_s, it is impossible to find t'_A with certainty.

Anyhow, it is possible to subtract the strains due to creep and the previously observed curved reconsolidation lines can be approximated with a constant K-modulus until σ'_{pc} is exceeded, subsequently the modulus decreases according to Eq. (6).

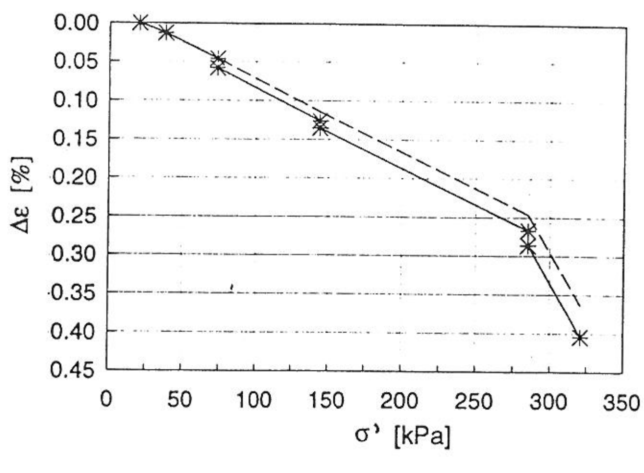

Figure 6: Reloading curve with creep included and reloading curve without creep (dotted line).

Oedometer tests have been performed with the actual clay till with a lot of un- and reloading curves to determine the influence of the width of the stress increments. It has been shown that the same slope of a reloading line can be found, regardless of the width of the stress increments.

Fig. 7 shows three different combinations of stress increments for the same unloading stress and preconsolidation pressure. Almost the same modulus of consolidation K is obtained. The mean value of K is 82 MPa.

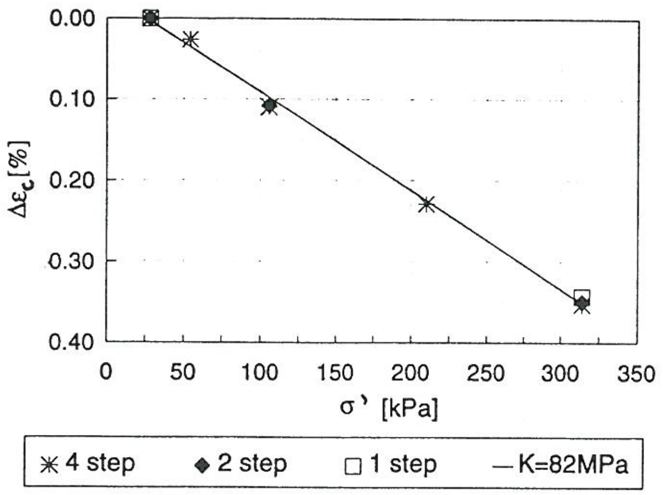

Figure 7: Reconsolidation line without creep. $OCR \approx 10$.

4 DETERMINATION OF σ'_{pc}

For many reasons it is important to determine the preconsolidation pressure σ'_{pc}. Both the primary- and creep deformations increase drastically when σ'_{pc} is exceeded and yielding occurs.

A suitable method is to calculate the variation of the modulus of consolidation K with the effective stress, according to Fig. 5. It is important that the K-modulus ($K = \Delta\sigma'/\Delta\epsilon_c$) only describes the pure primary consolidation process. It means that the deformations are cleaned for creep, according to the earlier mentioned method, both in the preconsolidated state and in the normally consolidated state. The method is a very precise method to determine σ'_{pc}, but it depends on the chosen widths of the stress increments.

Another method is to consider the variation of the arbitrary creep rate ϵ_s with the effective stress σ'. ϵ_s can be found by

$$\epsilon_s(t) = \frac{\partial\epsilon_{cr}(t)}{\partial logt} = Q_s\left(\frac{t}{t + t'_A + t_c}\right) \quad (8)$$

where Q_s is the residual creep rate (a constant), t_c the time of consolidation and t'_A the age of creep. For a certain stress-state $(\sigma'_A, \sigma'_{pc})$, t'_A can be found from Eq. (5) as

$$t'_A = t_c\left[exp\left(\frac{1}{\alpha}ln\frac{\sigma'_{pc}}{\sigma'_A} - \frac{ln10(\sigma'_{pc} - \sigma'_A)}{\alpha\, Q\, K_{pc}}\right) - 1\right] \quad (9)$$

If time curves on a recompression line are considered, ϵ_s at the same relative time, can be found from Eq. (8). ϵ_s will increase with the effective stress and remain a constant Q_s when the preconsolidation pressure σ_{pc} is exceeded, Fig. 8.

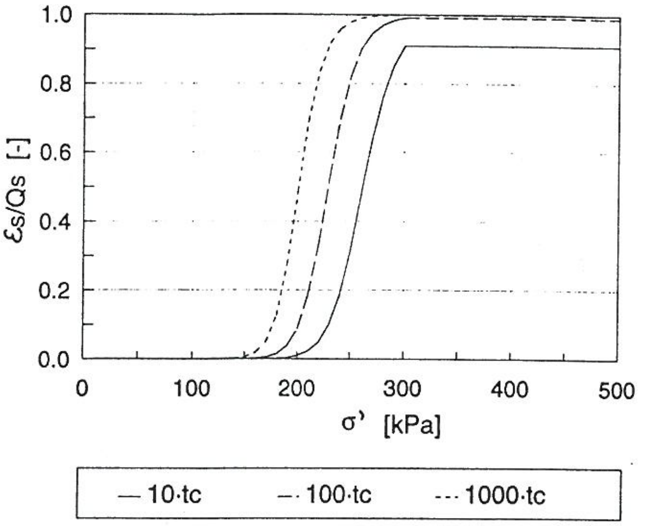

Figure 8: Determination of σ'_{pc} from the variation of the creep rate ϵ_s. $\sigma'_{pc} = 300$ kPa, $\alpha = 0.05, Q = 4\ \%, K_{pc} = 100$ MPa, $OCR \approx 10, t_c = 60$ min.

In principle the method to determine σ'_{pc} is similar to the method described by Akai.

5 CONCLUSION

For oedometer tests in the laboratory, where the time of consolidation is rather small, it is shown, that the consolidation- and creep processes can be separated by using statistics on the measured strains. All types of time curves can be analysed. The deformation model, especially describing creep, can be used with certainty for the normally categorised, normally consolidated clay and for slightly preconsolidated clay (OCR=1-2). For preconsolidated clay (OCR=2-10) creep and primary consolidation can be separated using the statistical program build on Eq. (7). However, it is impossible to find t'_A which means it is doubtful whether the preconsolidated state can be reached by creep from the normally consolidated state.

Further research is needed to determine whether the separation-method or a modified method can be applied for triaxial tests too.

REFERENCES

Akai, K. (1960): Die strukturellen Eigenschaften von Scluff. Mitteilungen Heft 22. Die Technishe Hochschule, Aachen.

Bjerrum, L. (1967): Engineering Geology of Norwegian Normally Consolidated Marine Clays as Related to Settlements of Buildings. Geotechnique 117, p. 81-118.

Brinch Hansen, J. (1961): A model law for simultaneous primary and secondary consolidation. GIB 13. Danish Geotechnical Institute.

Jacobsen, H. Moust. (1992): Karakteristiske belastningstilstande for moræneler. NGM-92, DGF-Bulletin 9.

Jørgensen M. B. (1992): Konsolideringsforløb med varierende konsolideringskoefficient. NGM-92, DGF-Bulletin 9.